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Aerotow

"Lowering the Cost of Space Launches"

NASA's Dryden Flight Research Center has helped demonstrate that a decades-old concept used to tow sailplanes into the air may help lower the cost of placing small satellites into low earth orbit.

The demonstration, called the Eclipse Project, brought together NASA, Kelly Space and Technology, of Redlands, Calif., and the U.S. Air Force in a joint experimental program that successfully tested the feasibility of using an aerotow system to pull a conceptual winged launch vehicle to an altitude high enough to launch small satellites into space.



An Air Force QF-106 aircraft was the towed aircraft in the Eclipse flight test project.

NASA Photo EC 97 43932-12

A Unique Concept

If the aerotow concept becomes operational, a large transport-size jet aircraft would tow a piloted glider-like launch vehicle into the air with a long robust towline. At a predetermined altitude, the launch vehicle weighing about 320,000 lbs would separate from the tow aircraft. The vehicle's rocket propulsion system would then be started to boost the vehicle to an altitude of about 400,000 feet where one or more small satellites would be released into low earth orbit. The launch vehicle would then reenter the atmosphere

where the pilot would use jet engines to fly the vehicle to a runway landing. The launch vehicle would then be serviced for another flight.

The test and demonstration program, carried out between 1996 and 1998 by NASA Dryden at Edwards AFB, Calif., used an Air Force C-141A Starlifter transport as the tow aircraft. A QF-106A Delta Dart was chosen as the towed aircraft to simulate a future launch vehicle because of its low-aspect ratio and relatively high wing loading. Following a period of modifications, tow system engineering and installation work, simulations, tests, and crew training, the delta-wing QF-106 was successfully towed aloft six times by the C-141 to a peak altitude of 25,000 feet to validate the aerotow concept.

The Eclipse concept is being promoted as a way to lower the weight and cost of a space launch vehicle. Using an aircraft to tow the launch vehicle to 30,000 or 40,000 feet eliminates the need for massive first-stage rockets to just get them off launch pads. The tow aircraft does the work of the first-stage rockets and the launch vehicle becomes a reusable winged spacecraft.

The founder of Kelly Space and Technology, Mike Kelly, patented the aerotow concept in 1997 under the title "Space Launch Vehicles Configured as Gliders and Towed to Launch Altitude by Conventional Aircraft."

A Brief Aerotow History

Using one aircraft to tow another, from takeoff to full flight and release, dates to World War I when it was first proposed by Anton Fokker, the Netherlands-born industrialist whose Germany factories built the famed Fokker D VII biplane, called the finest aircraft of that war. There is no evidence, however, that aerotow was used during World War I

for military purposes.

In the 1920s, Fokker's aerotow idea caught on with European sailplane pilots as a way of quickly achieving soaring altitude. When the glider is towed to a predetermined release altitude, the tow rope is released by the sailplane pilot who then relies on flying skills to stay aloft as long as possible. By the time the sport of soaring had spread to the United States, aerotowing had become the standard method of launching sailplanes throughout the world.

During World War II, Germany was the first to tow heavy aircraft into the air. The United States Army also towed gliders behind twin-engine transports as a way of delivering troops and light equipment over long distances to battlefields.

In the United States following World War II, experiments in aerotowing were conducted with a P-51 Mustang fighter, a small test version of the Northrop flying wing, and a T-33 jet trainer.

In the early 1960s, NASA Dryden used aerotowing to test its pioneering lightweight M2-F1 plywood lifting body to study the stability, control, and landing characteristics of the wingless vehicle design. The M2-F1 was towed from the dry lakebed at Edwards AFB with a NASA C-47 in a series of test flights that eventually reached about 10,000 feet before release from the 1000-foot towline. Subsequent tests of a later series of heavyweight lifting bodies, dropped from the wing pylon of the NASA B-52 carrier aircraft, generated data that helped in the development of the space shuttle.

The Joint Eclipse Project

Although the aerotow concept has been in use since the 1920s, there is a noticeable absence of scientific literature, engineering data, and flight-validated modeling related to any testing or

operational use, especially to data covering heavy aircraft. Several theoretical studies have been published, but there were no comprehensive comparisons with flight test data.

Once the patent was issued to Kelly Space and Technology on the use of aerotowing as a low-cost method of placing satellites into low-earth orbit, the company gained the support of the U.S. Air Force Research Laboratory to carry out a test and demonstration project using aircraft more representative of the conceptual vehicles. The joint test and demonstration team consisted of the Air Force Flight Test Center at Edwards AFB, and NASA's Dryden Flight Research Center, which managed and conducted the project.

Aircraft selected for the Eclipse project were a C-141A Starlifter transport, furnished by the Air Force Flight Test Center, and a pair of QF-106A Delta Dart aircraft. The F-106s were originally all-weather interceptors dating to the mid-1950s that had been converted into unpiloted drones and used for air-to-air missile training at Tyndall AFB, Florida. One of the QF-106s was modified as the project's primary towed aircraft and the second was a backup.

The main aspects of the project, which included modifications to the C-141A and the towed aircraft, were extensive ground testing to validate the structural integrity of the towing system, installation of a flight data instrumentation system, analytical studies to predict the towing and flight characteristics of both types of aircraft, and actual flight test operations.

Aircraft Modifications

The heart of the C-141A modifications was installation of an Air Force parachute extraction qualification pallet near the aft end of the aircraft's cargo bay. On the pallet was a mandrel to which the

QF-106 towline was attached. Built into the mandrel was a guillotine-like device, originally designed to cut nylon parachute straps during parachute extractions that cut the QF-106 towline once it was time to separate from the C-141A.

The clamshell cargo doors at the rear of the C-141A were removed for the project and the moveable cargo ramp was placed in a locked-up position. The pressure bulkhead door, normally used to pressurize the cargo bay during cruise flight, was also removed for the test project.

The main modification to the QF-106, besides requalifying it for piloted flight, was creating a nose-mounted tow mechanism on the aircraft that would withstand the loads and stresses of towed flight.



The F-106 towline attachment and release mechanism, mounted just forward of the cockpit canopy, is shown in this photo.

NASA Photo NASA EC 97 44233-5

An attach point called a weldment and a towline release mechanism was mounted on the upper fuselage just forward of the canopy. The release system was from a standard B-52 landing drag chute system that was modified to be actuated by the push of a button on the pilot's control stick. A manually operated backup towline release system was also added, with the handle installed in the cockpit.

The upper nose area and the sides of the fuselage were strengthened with aluminum and stainless steel skin doublers to help distribute tow loads and to bridge a major fuselage assembly point.

Instrumentation

Instrumentation to record all aspects of towed flight, including in-flight monitoring by project personnel in Dryden's mission control room, was installed on both aircraft. Each aircraft package was fully ground calibrated before flight operations.

Both aircraft received full suites of research data instrumentation to record speed and angular rates, control surface positions, elevation and azimuth angles, towline tension data, and engine performance.

Towline Assembly

The 1,000-foot long towline was made of liquid crystal polymer. It was 3/4-inch in diameter and had a strength equal to 2.25 times the design limit load during proof tests. The line also showed excellent wear resistance and a residual strength of nearly 1.5 times the design limit after being subjected to four life-time loads tests. Placed in the middle of the towline were two 50-foot nylon straps that served as a shock absorber during sudden incidents of tension to help ease pilot workload.

Carrying a copyrighted name of Vectran, the towline was attached to the mandrel on the C-141 with a 1.75-inch wide nylon strap. Connecting the nylon strap to the towline was a three-pin connector that allowed rapid assembly of the complete towline assembly during preflight operations.

At the QF-106 end of the towline was a frangible link -- one that would break for safety purposes when loads reached a certain limit. An adapter connected the frangible link to the release mechanism that was part of the weldment unit mounted on the upper fuselage.

Simulation

Before flight operations began, simulators were used to plan and verify each test event, including emergency procedures, so that no flight safety issue was overlooked. Examples of simulations were studies of towline tension during all phases of flight, from takeoff through towed aircraft release; trim conditions on the towed aircraft at various distances separating the two aircraft during flight; takeoff distances; and studies of what effect wake turbulence generated by the towplane would have on the QF-106.

Simulators were also used by project pilots to rehearse each planned event, and also emergency procedures such as the accidental release of the towed aircraft at low altitudes and at low airspeeds.

Flight Testing Aerotow

There were 14 flights in the program -- eight to accumulate in-flight data about wake turbulence, calibrate air data instrumentation, validate simulator predictions, and determine the optimum position of the QF-106 behind the tow aircraft. The remaining six flights were the towed missions which successfully demonstrated the aerotow concept.

On the first flight in October 1996, project officials used a Dryden F-18 to investigate wake turbulence behind the C-141A to begin selecting the best and safest QF-106 tow position. Two months later, with smoke generators mounted on the C-141A's wingtips, in-flight studies of wake turbulence and how it may impact the towed aircraft were carried out.

The first untethered pairing of the two project aircraft was in July 1997. During the flight, the QF-106 was flown about 1,000 feet behind and several hundred feet lower than the C-141A as project pilots and engineers examined potential wake turbulence and took a final look at the preferred F-106 tow location.

characteristics, and to give engineers a final instrumentation check. The pre-test series ended with a flight to calibrate air data instrumentation and a final validation of simulator predictions.

In December 1997, a successful high-speed taxi test with both aircraft linked by the towline was carried out. The test concluded with the release of the QF-106 during takeoff rotation and a final look at the takeoff characteristics of the C-141A configured as the tow aircraft.

The six towed test flights were carried out between December 1997 and February 1998.

Takeoff procedures were the same for each



A view of the F-106 and the C-141A shortly after takeoff on the first tethered test flight.

NASA Photo NASA EC98 44357-13

The next four flights with the QF-106 began in October 1997 with a functional check flight to validate simulator predictions and takeoff

towed flight. After the spooled towline was attached to the QF-106 and preflight checks were completed, both aircraft were taxied to predetermined positions

on the runway. The engine on the QF-106 was set at the idle power setting and remained there during the entire towed sequence to give the aircraft hydraulic and electrical power, and also thrust if an emergency release occurred. The towline was then unreeled, attached to the tow aircraft, and its brakes were locked. The C-141A was slowly moved forward to increase tension on the towline to 6,000 pounds. At that point the brakes on the C-141A were released, its engines were powered up, and brakes on the QF-106 were slowly released so that both aircraft moved in unison to keeping the towline taut during the takeoff roll.

Takeoff speed of the C-141A was about 132 mph. The QF-106 began rotating at 138 mph but remained on the runway until it reached a speed of 189 mph. By then, the tow aircraft was several hundred feet into the air and both were accelerating in speed.

During each flight, tests were carried out to study QF-106 handling qualities, turns, climb angles, towline tensions, and wake vortices and turbulence. Data were also obtained associated with towline "bungee" oscillations as varying forces caused it to stretch and contract.

Throughout the series of flights, tests were conducted at altitudes that ranged between 10,000 feet and 24,000 feet. The top speed of the C-141A was limited to 230 mph because of the removal of the rear cargo doors.

During most tow sequences the QF-106 flew about 300 feet lower than the C-141A, though it was as much as 400 feet lower on some tests to study "bungee" and lateral control conditions. During one test the QF-106 was placed 70 feet above the C-141A to check a high-tow position. Dynamic oscillations resulted.

Once the towed portion of each flight was completed, the usual release altitude of the QF-106 for its powered flight back to Edwards AFB was about 10,000 feet. The towline release mechanism on the QF-106 performed satisfactorily on each flight.

The towline was released from the C-141A at low altitude and allowed to fall to the ground before the aircraft was landed at Edwards AFB. During the separation phase, the behavior of the plummeting towline was also studied so that abrasion and damage could be minimized in any future projects.

Concept Conclusions

The joint Eclipse test project successfully demonstrated the feasibility of using the decades-old aerotow concept to launch future space vehicles.

The idea behind aerotow is that it takes much less effort to pull a load than it does to carry a load. The towing aircraft becomes a first-stage vehicle that pulls a second-stage launch vehicle up into the thinner atmosphere. Rocket engines then take over to send the winged vehicle out into space, followed by a conventional runway landing back on Earth.

An aerotow vehicle -- or fleet of vehicles -- could be used for a variety of tasks: launching satellites into low earth orbit, space sightseeing enterprises, or brief scientific missions to study events and objects in space and also on Earth below.

The joint cooperation displayed between the project partners -- NASA, Kelly Space and Technology, and the U.S. Air Force -- could one day emerge as the foundation behind commercial ventures that may substantially lower the development and operational costs of spaceflight.